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Central-Axis ^{60}CO Ionization Measurements in Graphite As A Function of Phantom Diameter, Depth, and Field Size

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

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Abstract

Ionization measurements along the central axis were made in a graphite phantom irradiated with cobalt-60 gamma rays. The measurements were made under the following conditions: phantom diameters of 15, 20, and 30 cm; 15 depths from 1 to 39 g/cm^2; and square field sizes of 8.3, 10.5, 12.4, and 17.4 cm at a fixed detector position of 1 m from the source. Empirical fits to the data aid in correcting calorimeter comparisons to a common geometry.

Key Words: Absorbed dose; cobalt-60; graphite; calorimeter comparisons; phantom size.

I. INTRODUCTION

In view of the importance of achieving accurate and uniform measurements in radiation therapy and radiation protection, and because those goals are linked to comparisons of calorimetric primary standards, this investigation was initiated to aid in the comparison of calorimeters constructed of graphite and irradiated with cobalt-60 gamma rays. Because comparisons of those instruments will be meaningful only if they refer to a common geometry, an investigation was made to study the variation of absorbed dose in graphite along the central axis as a function of phantom diameter, depth of measurement, field size, and backscattering thickness. This investigation required ionization measurements using 185 experimental setups: phantom diameters of 15, 20, and 30 cm; 15 depths from 1 to 39 g/cm^2; and square field sizes of 8.3,

10.5, 12.4, and 17.4 cm. The data permit interpolation between those values including approximate extrapolations to an infinite diameter phantom. The smallest phantom diameter of 15 cm was that of the National Bureau of Standards (NBS) graphite calorimeter [1]. When calorimeters of different diameters are compared, correction factors must be specially determined, such as in the recent BNM-LMRI/NBS comparison [2] where a correction was applied to measurements made with a 3-cm diameter calorimeter for comparison with measurements made with the NBS 15-cm diameter calorimeter.

A program for the international comparison of absorbed-dose calorimeters has been established at the Bureau International des Poids et Mesures (BIPM). All calorimetric measurements must be compared with the BIPM graphite ionization chamber, enclosed by a 30-cm diameter phantom, which is the intermediary instrument for the calorimetric comparisons. This investigation will aid in correcting measurements to a specified, or to an infinite, diameter phantom.

II. EXPERIMENTAL SETUP

Figure 1 shows the experimental setup. A spherical graphite ionization chamber (similar to the one described in reference [3]), 1.27 cm inner diameter, was enclosed near the front surface of a graphite phantom, 15.2 cm diameter by 10.0 cm thick, which are the outside dimensions of the NBS calorimeter. The distance between the graphite ion collecting electrode and the cobalt-60 source was kept fixed at 1 m. Measurements were made at different depths by laying

graphite discs (1.7 g/cm^3), 15.2 cm in diameter and of various thickness, on the phantom. Measurements were also made by enclosing those bodies with graphite sleeves, one 20.3 cm outside diameter by 15.3 cm inner diameter, and another of 30.5 cm outside diameter by 15.3 cm inner diameter. Height adjustment screws permitted the sleeves to be raised or lowered so that their top surfaces were at the same height as the top surface of the 15.2 cm diameter disc nearest to the source. Three 2.5 cm thick graphite rings (r_1, r_2, and r_3) were raised, one at a time, and placed against the rear of the graphite block simulating the NBS portable calorimeter to determine if the graphite behind the ion chamber provided an essentially infinite backscattering thickness. The placement and removal of all the massive pieces of graphite caused small deflections in the wooden supports. However, the distance between the source and collecting electrode was always fixed within 0.025 mm by means of an adjusting nut (not shown) until the dial indicator showed that the collecting electrode returned to its initial position.

Beam profile measurements were made of the four square field sizes by exposing film in air at 1 m from the source, and then measuring the film density along lines bisecting opposite sides. The distances (in centimeters) across the 90% and the 50% points of central density were, respectively, 5.3 and 8.3, 7.4 and 10.5, 9.5 and 12.4, and 14.3 and 17.4. The beam sizes at the 50% points are used in this report.

III. RESULTS

Measurements showed that the backscattering ring (r_1) increased the response by (0.07 $\pm$ 0.03)%, and that there was no further significant increase in response with ring r_2 also in position. All three rings (r_1, r_2, and r_3) were in position during the following measurements.

A complicated factor that affects the detector response is geometry, such as the square field sizes that range from being larger in area to being much smaller than the circular phantom cross sections. Another is the unknown effects of collimator-scattered and leakage radiation that can vary with different source heads over the phantom front surface. These considerations, the small increase in detector response with phantom diameter, plus the fact that only three measurements made were at a given depth, make it clear that the infinite diameter response can be estimated only roughly. Fortunately, the further increase in response beyond the largest (30 cm) phantom size is quite small, and this is not an important region because phantoms of larger diameter are not in use in international comparisons. Nevertheless, it is still of some interest to estimate the correction to infinite phantom diameter, however rough that estimate may be. Empirical fits to the data points seemed adequate. The relative current is plotted against the reciprocal of the square of the phantom diameter in Figure 2. The measurements were made at a depth of 4.7 g/cm^2 and with the 10.5 cm field, close to standard conditions for international comparison of calorimeters. The increase in current is only 0.5% when the phantom diameter, D, is increased from 15 to 30 cm. A useful equation for the range of $15 \leq D \leq 30$ cm is of the type:

$$Y_\alpha = a_o + a_1X + a_2X^2, \text{ where } X = D^{-2}.$$

In this range, the curve has no point of inflexion which is a reasonable physical expectation. The numerical coefficients of this equation are tabulated in Tables 1 to 4. This equation with three constant coefficients passes, of course, through the three data points, but the change in detector response as a function of D (at a particular depth) is not determined from any such single curve. It is determined from results derived from the curves (Y_α) plotted as a function of depth. An illustrative example is given below.

Tables 1 to 4 summarize the results of the measurements, corrected for cobalt-60 decay. Column 1 lists the depth of measurement, and column 2 lists the diameters of the phantom as D(1), D(2), and D(3), where

$$D(1) = 15.24 \text{ cm}, \quad D(2) = 20.32 \text{ cm}, \text{ and } D(3) = 30.48 \text{ cm}.$$

Column 3 lists the relative measured ionization chamber current. Column 4 shows the percent current increase relative to the 15.2 cm diameter phantom. Columns 5 to 7 list the coefficients of the equation $Y_\alpha = a_o + a_1X + a_2X^2$ calculated from the three values of D^{-2} and Y shown in columns 2 and 3. Table 5 shows the percent increase in response calculated from equations Y_α and Y_β when the phantom is increased from 30.5 cm to infinite diameter.

Other empirical fits to the data can be made. An equation of the type:

$$Y_\beta = b_o + b_2X^2 + b_4X^4$$

also passes through the data points, but most of the curves resulted in points of inflexion in the range of $15 \leq D \leq 20$ cm. Mainly for this reason, the coefficients of Y_β were not included in Tables 1 to 4. However, the curves, Y_α and Y_β, were used to compare calculated response increases when a 30.5 cm diameter phantom is increased to infinite diameter.

The central axis measurements for each field and phantom size as a function of depth were least-squares fitted to the polynomial:

$$y = c_o + c_1x + c_2x^2 + c_3x^3 + c_4x^4,$$

where y is the detector response and x is depth in mass per unit area, determined from micrometer and mass measurements of the 15.2 cm diameter plates. The coefficients are listed in Table 6 for the different field sizes and phantom diameters shown in columns 1 and 2, respectively.

Figure 3 is an illustrative example that shows the calculated difference in response of an 18 cm diameter calorimeter compared to one of 15 cm diameter for the 10.5 x 10.5 cm field. The percent increase in response of the former is plotted as a function of the measurement depth, x. The points were calculated from the equation for Y_α, the coefficients of which are listed in Table 2. The points are represented by the linear equation $y = 0.021x + 0.13$.

The cobalt-60 source was in an Eldorado Super G head manufactured by Atomic Energy of Canada Limited. It is important to note that the results might have been somewhat different, if the experiment had been done with a different source head but with the same field dimensions, because of differences in scattering and energy spectral distributions incident on the phantom. Thus the results reported here are, at best, an approximation for correcting two different diameter calorimeters if they are compared in another cobalt-60 source apparatus.

IV. SUMMARY

Comparison of calorimeters requires corrections to identical irradiation conditions. This investigation aids in determining those corrections from ionization measurements made under the following conditions: phantom diameters of 15, 20, and 30 cm; 15 depths from 1 to 39 g/cm^2; square field sizes of 8.3, 10.5, 12.4, and 17.4 cm at the 50% points; a fixed source-detector distance of 1 m; and saturated back-scattering thickness.

V. ACKNOWLEDGEMENT

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Table 1. Results with an 8.3 x 8.3 cm ^{60}Co field

Graphite Depth (g/cm^2)	Phantom Diameter (cm)	Relative Current Y*	Increase from a 15.2 cm dia. Phantom (%)	Coefficients of $Y_c = a_0 + a_1X + a_2X^2$		
				a_0	a_1	a_2
1.4	D(1) = 15.24	28.710 06 4	0.00			
	D(2) = 20.32	28.748 16 5	0.13	28.768	-17.2	-2700
	D(3) = 30.48	28.763 09 4	0.18			
2.0	D(1)	28.255 08 4	0.00			
	D(2)	28.289 10 3	0.12	28.301	2.0	-2900
	D(3)	28.300 12 6	0.16			
2.9	D(1)	27.631 19 4	0.00			
	D(2)	27.670 08 3	0.14	27.702	-9.6	-1600
	D(3)	27.690 05 4	0.21			
4.7	D(1)	26.079 19 4	0.00			
	D(2)	26.126 06 3	0.18	26.146	1.2	-3900
	D(3)	26.143 15 3	0.24			
6.4	D(1)	24.559 02 2	0.00			
	D(2)	24.596 01 2	0.15	24.650	-21.4	0
	D(3)	24.629 08 3	0.28			
8.8	D(1)	22.485 08 3	0.00			
	D(2)	22.539 12 3	0.24	22.588	-15.6	-1930
	D(3)	22.569 00 3	0.37			
11.3	D(1)	20.162 28 3	0.00			
	D(2)	20.241 07 3	0.39	20.300	-14.9	-4000
	D(3)	20.280 12 3	0.58			
14.0	D(1)	18.066 14 3	0.00			
	D(2)	18.123 18 3	0.32	18.181	-20.1	-1560
	D(3)	18.158 03 3	0.51			
17.5	D(1)	15.237 04 3	0.00			
	D(2)	15.303 20 4	0.44	15.368	-21.9	-1990
	D(3)	15.342 02 3	0.69			
21.4	D(1)	12.614 22 3	0.00			
	D(2)	12.673 02 3	0.47	12.750	-31.8	0
	D(3)	12.716 08 3	0.81			
24.7	D(1)	10.642 06 3	0.00			
	D(2)	10.704 20 3	0.59	10.763	-19.6	-2000
	D(3)	10.740 09 3	0.92			
28.1	D(1)	8.937 21 4	0.00			
	D(2)	8.996 14 3	0.66	9.067	-28.4	- 430
	D(3)	9.036 26 3	1.11			
31.9	D(1)	7.264 17 3	0.00			
	D(2)	7.314 26 3	0.70	7.381	-27.5	0
	D(3)	7.352 10 3	1.22			
35.7	D(1)	5.978 10 2	0.00			
	D(2)	6.021 03 2	0.72	6.081	-24.1	0
	D(3)	6.056 11 3	1.30			
39.1	D(1)	4.950 09 3	0.00			
	D(2)	4.990 18 3	0.81	5.044	-21.9	0
	D(3)	5.021 11 5	1.43			

* The first entry is 28.710 with a mean error of 0.006% for the mean of 4 measurements.

Table 2. Results with a 10.5 x 10.5 cm ^{60}Co Field

Graphite Depth (g/cm^2)	Phantom Diameter (cm)	Relative Current Y	Increase from a 15.2 cm dia. Phantom (%)	Coefficients of $Y_\alpha = a_o + a_1X + a_2X^2$ a_o	a_1	a_2
1.4	D(1) = 15.24	29.332 12 3	0.00			
	D(2) = 20.32	29.393 14 5	0.21	29.435	-8.7	-3500
	D(3) = 30.48	29.421 05 3	0.30			
2.0	D(1)	28.893 22 4	0.00			
	D(2)	28.951 10 3	0.20	29.021	-27.7	-460
	D(3)	28.991 14 4	0.34			
2.9	D(1)	28.305 08 3	0.00			
	D(2)	28.374 12 4	0.25	28.400	3.9	-6050
	D(3)	28.398 22 3	0.33			
4.7	D(1)	26.816 11 4	0.00			
	D(2)	26.899 04 3	0.31	26.963	-16.4	-4140
	D(3)	26.941 13 3	0.47			
6.4	D(1)	25.356 16 4	0.00			
	D(2)	25.443 27 3	0.34	25.521	-24.2	-3290
	D(3)	25.491 07 3	0.53			
8.8	D(1)	23.366 12 3	0.00			
	D(2)	23.469 05 3	0.44	23.543	-17.2	-5570
	D(3)	23.518 25 4	0.65			
11.3	D(1)	21.127 05 3	0.00			
	D(2)	21.216 25 4	0.42	21.337	-49.0	0
	D(3)	21.286 19 3	0.75			
14.0	D(1)	19.042 07 4	0.00			
	D(2)	19.141 25 3	0.52	19.245	-37.2	-2320
	D(3)	19.202 02 3	0.84			
17.5	D(1)	16.202 03 3	0.00			
	D(2)	16.309 09 3	0.66	16.415	-36.8	-2960
	D(3)	16.372 07 3	1.05			
21.4	D(1)	13.527 22 3	0.00			
	D(2)	13.640 17 3	0.84	13.746	-34.4	-3830
	D(3)	13.705 09 3	1.31			
24.7	D(1)	11.495 11 3	0.00			
	D(2)	11.601 07 3	0.92	11.706	-36.2	-3000
	D(3)	11.664 10 3	1.47			
28.1	D(1)	9.707 12 3	0.00			
	D(2)	9.806 08 3	1.01	9.904	-34.3	-2670
	D(3)	9.864 07 3	1.62			
31.9	D(1)	7.940 09 3	0.00			
	D(2)	8.024 21 3	1.06	8.139	-46.6	0
	D(3)	8.091 22 3	1.90			
35.7	D(1)	6.567 10 3	0.00			
	D(2)	6.642 11 3	1.14	6.740	-40.1	0
	D(3)	6.697 15 3	1.97			
39.1	D(1)	5.458 11 3	0.00			
	D(2)	5.527 11 3	1.26	5.618	-37.3	0
	D(3)	5.579 29 4	2.21			

Table 3. Results with a 12.4 x 12.4 cm ^{60}Co Field

Graphite Depth (g/cm^2)	Phantom Diameter (cm)	Relative Current Y	Increase from a 15.2 cm dia. Phantom (%)	Coefficients of $Y_\alpha = a_0 + a_1X + a_2X^2$ a_0	a_1	a_2
1.4	D(1) = 15.24	29.675 14 8	0.00			
	D(2) = 20.32	29.768 06 7	0.31	29.817	-3.8	-6790
	D(3) = 30.48	29.805 13 7	0.44			
2.0	D(1)	29.246 13 9	0.00			
	D(2)	29.349 07 7	0.35	29.389	4.5	-8740
	D(3)	29.384 09 8	0.47			
2.9	D(1)	28.672 10 9	0.00			
	D(2)	28.772 36 9	0.35	28.838	-12.2	-6100
	D(3)	28.818 06 7	0.51			
4.7	D(1)	27.218 06 6	0.00			
	D(2)	27.333 11 8	0.42	27.428	-27.4	-4950
	D(3)	27.393 08 7	0.64			
6.4	D(1)	25.788 13 7	0.00			
	D(2)	25.919 13 8	0.51	25.986	-4.2	-9660
	D(3)	25.970 05 4	0.70			
8.8	D(1)	23.821 17 5	0.00			
	D(2)	23.970 17 5	0.63	24.053	-8.8	-10500
	D(3)	24.031 03 4	0.88			
11.3	D(1)	21.614 14 4	0.00			
	D(2)	21.765 10 4	0.70	21.869	-21.6	-8740
	D(3)	21.835 06 4	1.03			
14.0	D(1)	19.538 12 4	0.00			
	D(2)	19.706 05 4	0.86	19.834	-32.0	-8540
	D(3)	19.790 08 7	1.29			
17.5	D(1)	16.705 11 4	0.00			
	D(2)	16.867 23 5	0.97	16.995	-34.5	-7620
	D(3)	16.949 14 4	1.46			
21.4	D(1)	14.024 05 4	0.00			
	D(2)	14.180 03 4	1.12	14.310	-37.4	-6790
	D(3)	14.262 24 5	1.70			
24.7	D(1)	11.955 05 4	0.00			
	D(2)	12.107 09 4	1.27	12.203	-15.5	-9750
	D(3)	12.175 18 6	1.84			
28.1	D(1)	10.134 06 5	0.00			
	D(2)	10.271 07 5	1.36	10.390	-35.8	-5520
	D(3)	10.346 14 5	2.09			
31.9	D(1)	8.318 06 4	0.00			
	D(2)	8.444 07 4	1.52	8.559	-35.7	-4740
	D(3)	8.516 09 4	2.37			
35.7	D(1)	6.908 12 4	0.00			
	D(2)	7.014 08 4	1.54	7.112	-44.1	-1770
	D(3)	7.082 14 4	2.51			
39.1	D(1)	5.762 10 4	0.00			
	D(2)	5.856 11 6	1.64	5.955	-35.4	-2220
	D(3)	5.914 02 4	2.65			

Table 4. Results with a 17.4 x 17.4 cm ^{60}Co Field

Graphite Depth (g/cm^2)	Phantom Diameter (cm)	Relative Current Y	Increase from a 15.2 cm dia Phantom (%)	Coefficients of $Y_\alpha = a_o + a_1X + a_2X^2$ a_o	a_1	a_2
1.4	D(1) = 15.24	30.661 09 3	0.00	31.151	-49.2	-15000
	D(2) = 20.32	30.944 12 4	0.92			
	D(3) = 30.48	31.081 04 3	1.37			
2.0	D(1)	30.234 21 3	0.00	30.722	-2.9	-25700
	D(2)	30.565 09 3	1.09			
	D(3)	30.690 18 4	1.51			
2.9	D(1)	29.674 17 4	0.00	30.235	-30.8	-23100
	D(2)	30.025 09 3	1.18			
	D(3)	30.175 01 3	1.69			
4.7	D(1)	28.239 11 4	0.00	28.912	-42.7	-26400
	D(2)	28.654 07 3	1.47			
	D(3)	28.835 06 3	2.11			
6.4	D(1)	26.822 08 3	0.00	27.571	-47.7	-29300
	D(2)	27.283 20 5	1.72			
	D(3)	27.486 09 3	2.48			
8.8	D(1)	24.887 07 3	0.00	25.699	-24.7	-38100
	D(2)	25.416 11 3	2.13			
	D(3)	25.628 13 3	2.98			
11.3	D(1)	22.689 11 3	0.00	23.593	-4.3	-47800
	D(2)	23.302 10 3	2.70			
	D(3)	23.533 09 3	3.72			
14.0	D(1)	20.653 12 3	0.00	21.582	6.6	-51600
	D(2)	21.295 21 4	3.11			
	D(3)	21.529 09 3	4.24			
17.5	D(1)	17.823 07 3	0.00	18.820	4.1	-54800
	D(2)	18.509 00 3	3.85			
	D(3)	18.761 04 3	5.26			
21.4	D(1)	15.107 20 3	0.00	16.076	21.9	-57360
	D(2)	15.793 04 3	4.54			
	D(3)	16.033 23 3	6.13			
24.7	D(1)	12.996 04 3	0.00	13.947	9.3	-53500
	D(2)	13.656 19 4	5.08			
	D(3)	13.895 25 4	6.92			
28.1	D(1)	11.116 08 3	0.00	12.012	0.1	-48320
	D(2)	11.728 07 3	5.51			
	D(3)	11.956 33 3	7.56			
31.9	D(1)	9.222 08 3	0.00	10.035	0.4	-44000
	D(2)	9.778 04 3	6.03			
	D(3)	9.985 11 3	8.27			
35.7	D(1)	7.721 06 3	0.00	8.452	-13.6	-36300
	D(2)	8.207 19 3	6.29			
	D(3)	8.396 08 3	8.74			
39.1	D(1)	6.493 04 3	0.00	7.122	-1.5	-33600
	D(2)	6.921 16 4	6.59			
	D(3)	7.081 12 4	9.06			

Table 5. Percent increase in detector response when a 30.5 cm diameter phantom is increased to infinite diameter*

	Side of square field (cm)							
	8.3		10.5		12.4		17.4	
Depth (g/cm^2)	Y_α (%)	Y_β (%)	Y_α (%)	Y_β (%)	Y_α (%)	Y_β (%)	Y_α (%)	Y_β (%)
1.4	0.08	0.01	0.05	0.03	0.04	0.03	0.23	0.13
2.0	0.00	0.01	0.11	0.04	0.02	0.03	0.11	0.11
2.9	0.04	0.02	0.01	0.02	0.07	0.04	0.20	0.14
4.7	0.01	0.02	0.08	0.04	0.13	0.06	0.27	0.17
6.4	0.09	0.04	0.12	0.05	0.06	0.05	0.31	0.20
8.8	0.08	0.04	0.11	0.06	0.09	0.07	0.28	0.22
11.3	0.10	0.05	0.25	0.10	0.15	0.09	0.26	0.26
14.0	0.13	0.06	0.22	0.09	0.22	0.11	0.25	0.28
17.5	0.17	0.07	0.26	0.11	0.27	0.13	0.32	0.35
21.4	0.27	0.11	0.30	0.13	0.34	0.16	0.28	0.39
24.7	0.22	0.10	0.36	0.16	0.23	0.14	0.37	0.45
28.1	0.34	0.14	0.41	0.18	0.44	0.20	0.47	0.50
31.9	0.40	0.15	0.62	0.25	0.52	0.23	0.51	0.54
35.7	0.43	0.17	0.65	0.25	0.70	0.27	0.68	0.60
39.1	0.47	0.18	0.72	0.29	0.69	0.27	0.57	0.59

* Calculated from $Y_\alpha = a_o + a_1X + a_2X^2$ and $Y_\beta = b_o + b_2X^2 + b_4X^4$, where $X = D^{-2}$.

Table 6. Summary of central axis detector response

Field Size (cm)	Phantom Diameter (cm)	Equation Coefficients*				
		c_o	$10\ c_1$	$10^2 c_2$	$10^4 c_3$	$10^6 c_4$
8.3	D(1) = 15.24	29.855	-7.481	-1.775	9.125	-9.878
"	D(2) = 20.32	29.883	-7.446	-1.777	9.080	-9.800
"	D(3) = 30.48	29.889	-7.399	-1.802	9.141	-9.861
10.5	D(1)	30.389	-6.946	-1.912	8.843	-9.163
"	D(2)	30.441	-6.881	-1.933	8.852	-9.153
"	D(3)	30.460	-6.820	-1.962	8.914	-9.206
12.4	D(1)	30.702	-6.736	-1.947	8.650	-8.794
"	D(2)	30.780	-6.635	-1.976	8.629	-8.716
"	D(3)	30.807	-6.574	-1.997	8.646	-8.708
17.4	D(1)	31.677	-6.677	-1.848	7.999	-7.976
"	D(2)	31.916	-6.288	-1.871	7.561	-7.278
"	D(3)	32.017	-6.084	-1.971	7.769	-7.475

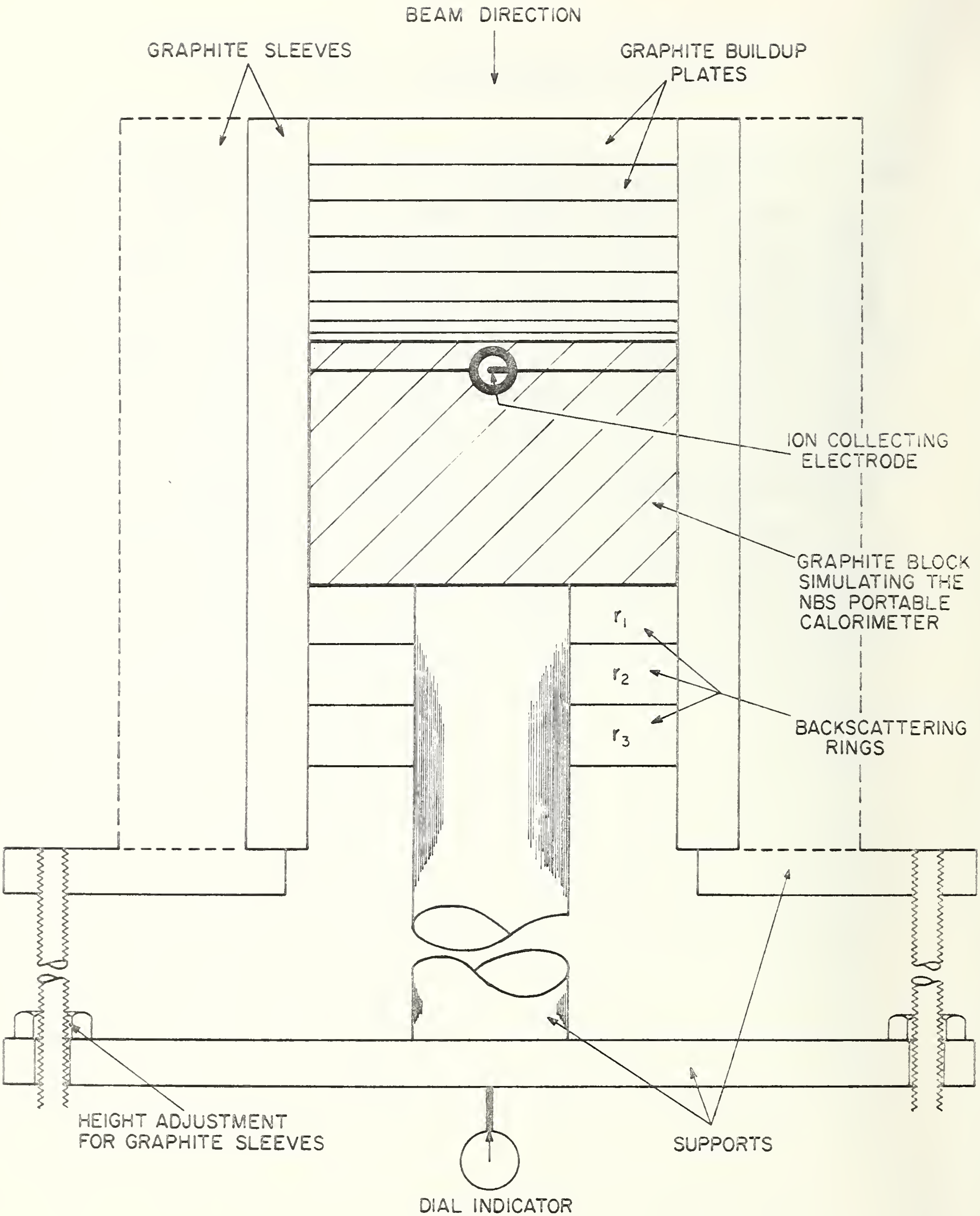
* $y = c_o + c_1 x + c_2 x^2 + c_3 x^3 + c_4 x^4$, where x is the depth in g/cm^2.

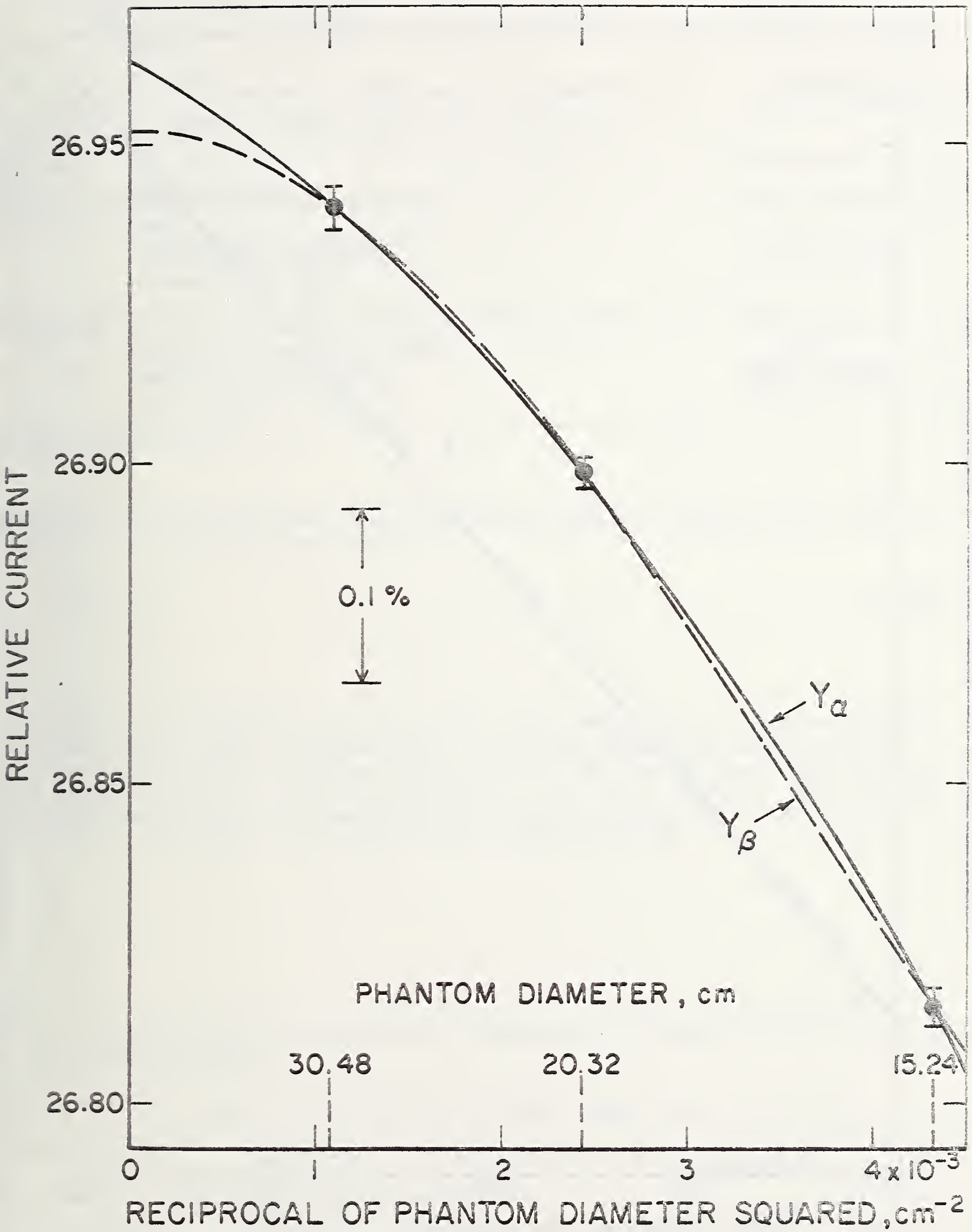
FIGURE LEGENDS

Fig. 1 Experimental setup for determining the ionometric response as a function of phantom diameter, depth, field size, and back-scattering thickness. The ion chamber was fixed at 1 m from the source and centered on the beam axis.

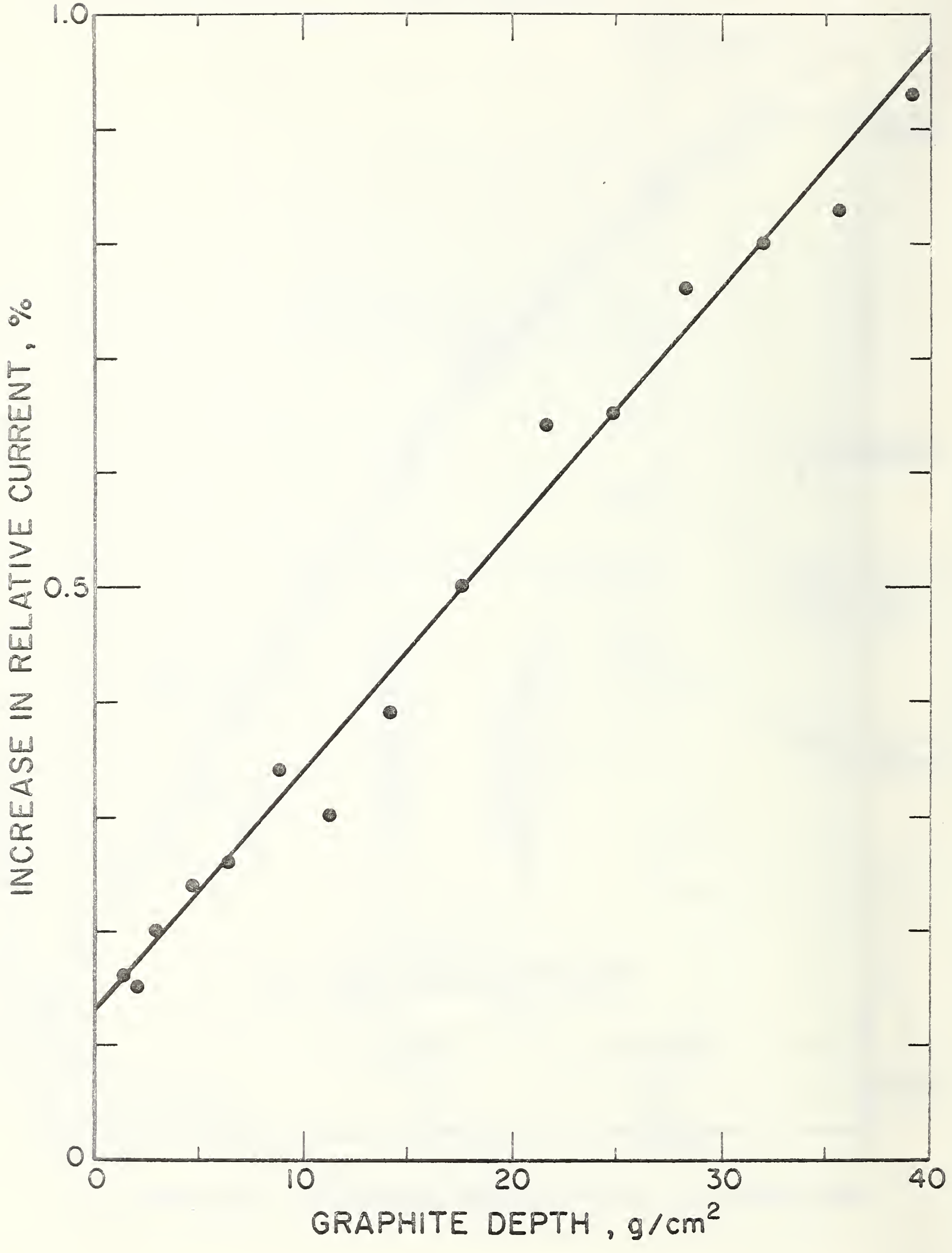
Fig. 2 Relative current as a function of phantom diameter at a depth of 4.7 g/cm^2, with a field size of 10.5 x 10.5 cm in air at 1 m.

Fig. 3 Illustrative example showing the percent increase in central axis absorbed-dose rate in an 18 cm diameter calorimeter compared to one of 15 cm diameter, for a 10.5 x 10.5 cm field in air at 1 m, in a cobalt-60 γ-ray beam.


BEAM DIRECTION
GRAPHITE SLEEVES
GRAPHITE BUILDUP PLATES
ION COLLECTING ELECTRODE
GRAPHITE BLOCK SIMULATING THE NBS PORTABLE CALORIMETER
r_1
r_2
r_3
BACKSCATTERING RINGS
HEIGHT ADJUSTMENT FOR GRAPHITE SLEEVES
SUPPORTS
DIAL INDICATOR



RELATIVE CURRENT
26.95
26.90
26.85
26.80
0.1 %
Y_α
Y_β
PHANTOM DIAMETER, cm
30.48
20.32
15.24
0
1
2
3
4×10^{-3}
RECIPROCAL OF PHANTOM DIAMETER SQUARED, cm^{-2}



1.0
0.5
0
INCREASE IN RELATIVE CURRENT, %
0
10
20
30
40
GRAPHITE DEPTH, g/cm^2

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Ionization measurements along the central axis were made in a graphite phantom irradiated with cobalt-60 gamma rays. The measurements were made under the following conditions: phantom diameters of 15, 20, and 30 cm; 15 depths from 1 to 39 g/cm^2; and square field sizes of 8.3, 10.5, 12.4, and 17.4 cm at a fixed detector position of 1 m from the source. Empirical fits to the data aid in correcting calorimeter comparisons to a common geometry.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Absorbed dose; cobalt-60; graphite; calorimeter comparisons; phantom size.

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